

**Crave the Wave B**  
**Cobra Invitational Science Olympiad 2016**  
**1/30/2016**

School Name: \_\_\_\_\_

Team Name: \_\_\_\_\_ Team Number: \_\_\_\_\_

Team Members: \_\_\_\_\_

- Carefully read the rules below
  - Clearly write your school name and team information.
  - Do not turn this page until told to do so.
  - Follow instructions to Start and Stop the exam.
  - No electronic device except calculators are allowed
  - All work must be legible and you must show your work to receive maximum points. Only partial points will be awarded for correct answers if the calculation steps are missing.
  - Answers without units will be considered incorrect.
  - Only use the constant value provided below to answer your questions
  - Assume the velocity of light in the air is equal to that in the vacuum and is equal to  $3 \times 10^8$  m/sec
  - Assume the velocity of sound in air is equal to 343 m/sec
  - Assume refractive index of air, water and diamond are 1, 1.333 and 2.42 respectively
  - Assume bulk modulus of water and steel are  $2.2 \times 10^9$  Pa and  $159 \times 10^9$  Pa respectively
  - Assume density of water and steel are  $1000 \text{ kg/m}^3$  and  $7861 \text{ kg/m}^3$
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## MULTIPLE CHOICE QUESTIONS (1 point each)

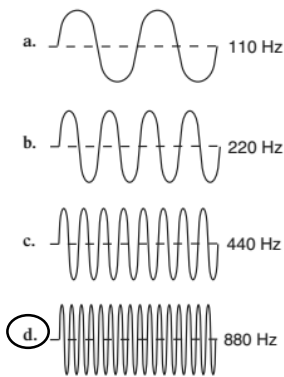
**Instruction:** Circle the best possible answer from the four choices –

1. Alex is watching the 4<sup>th</sup> of July fireworks display. He notices that he sees the flashes of light before he hears the explosion. This happens because –
- ☒ a. the light from the fireworks travels faster than the sound from the explosion
  - b. the sound from the explosion travels faster than the light from the fireworks
  - c. Alex sees better than he hears
  - d. the fireworks are moving away from Alex

2. Which of these processes enables the boy to see over the wall?
- a. Diffraction
  - b. Interference
  - ☒ c. Reflection
  - d. Refraction



3. Which sound would have the highest pitch?



4. A wave is transporting energy from left to right. The particles of the medium are moving back and forth in a leftward and rightward direction. This type of wave is called
- a. mechanical
  - ☒ b. longitudinal
  - c. electromagnetic
  - d. transverse

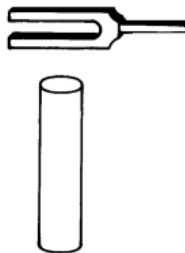
5. Which of the following is not a property of mechanical waves?
- a. moves around corners
  - b. uses matter to transfer energy
  - c. moves in the form of waves
  - ☒ d. does not require matter to carry energy
6. Police can detect speeding motorists with a radar gun. What property of waves enables them to do this?
- ☒ a. Waves reflect off an object and return with higher frequency.
  - b. Waves slow down when they strike an object.
  - c. Waves bend around barriers.
  - d. Two waves combine, travel together, and form a new wave.
7. Which of the following is not an example of diffraction?
- a. light bending between two pencils
  - b. water waves bending around a boat
  - ☒ c. light bouncing off a mirror
  - d. water waves bending around a pier
8. If the amplitude of a wave is increased by 3 times, then the energy of the wave
- a. Decreased by 3 times
  - b. Increased by 3 times
  - c. Decreased by 6 times
  - ☒ d. Increased by 9 times
9. Frequency is the number of wavelengths that pass a point in one second. A student was asked to measure the frequency of a wave. The frequency she recorded was most likely measured in
- a. meter
  - ☒ b. hertz
  - c. second
  - d. gram
10. A photon of which electromagnetic radiation has the most energy?
- a. Ultraviolet
  - ☒ b. X ray
  - c. Infrared
  - d. Microwave

11. An astronomical body emitting high-intensity pulses of green light is moving toward Earth at high velocity. To an observer on Earth, this light may appear

- a. Red
- ☒ b. Blue
- c. Orange
- d. Yellow

12. When a vibrating tuning fork is placed over an air column 16 centimeters long and closed on one end, the sound becomes louder. The wavelength of the sound produced is –

- ☒ a. 64 cm
- b. 32 cm
- c. 16 cm
- d. 4 cm



**FILL IN THE BLANKS QUESTIONS (1 points each)**

**Instruction:** Write your answer in the blank space to complete the sentence –

13. The length of time it takes a point on a medium carrying a wave to go through one full cycle is the period of the wave.
14. The individual colors in a rainbow appear separated because of dispersion of light.
15. Two points on a wave that are a half wavelength apart are 180° degrees out of phase with each other.
16. Light propagation in an optical fiber is due to total internal reflection of light.
17. Diffraction around corners is greater when the wavelength is larger.
18. If you are moving toward the source of sound, the frequency you perceive will be higher than that emitted by the source.
19. A point of maximum destructive interference is called a (an) node.
20. In a standing wave in a rope, the distance from a node to the next anti-node is one fourth the wavelength.

## NUMERICAL QUESTIONS (5 points each) –

**Instruction:** Show your calculation and draw a circle around the final answer –

21. In the air if a wave's wavelength is 2.4 m and its period is 1.8 sec, find its frequency and speed. If the wave enters water from air, what is the new wavelength?

$$\text{Frequency} = 1 / \text{period} = 1 / 1.8 \text{ Hz} = 0.5556 \text{ Hz}$$

$$\text{Speed} = \text{wavelength} * \text{frequency} = 2.4 \text{ m} * 0.5556 \text{ Hz} = 1.3333 \text{ m/sec}$$

$$\text{Using Snell's law} - N_{\text{air}}/N_{\text{water}} = L_{\text{water}}/L_{\text{air}} \text{ [N is the refractive index, L is the wavelength]}$$

$$L_{\text{water}} = L_{\text{air}} * (N_{\text{air}}/N_{\text{water}}) = 2.4 * (1/1.333) \text{ m} = 1.8 \text{ m}$$

22. The sound from a bolt of lightning is heard 10 seconds after you see the flash. How far away was the lightning strike (in meters)? Assume it takes 0 sec. for the light to travel this distance.

Distance of the lightning = speed of sound X delay in number of seconds between seeing the flash and hearing the sound

$$\text{Distance of the lightning} = 343 \text{ m/s} * 10 \text{ s} = 3430 \text{ m}$$

23. A surfacing whale in an aquarium produces water wave crests having an amplitude of 1.2 meters every 0.40 second. If the water wave travels at 4.5 meters per second, what is the wavelength and frequency of the wave?

$$\text{Period of the wave} = 0.40 \text{ sec}$$

$$\text{Frequency of the wave} = 1 / \text{period} = 1/0.4 = 2.5 \text{ hz}$$

$$\text{Speed of the wave} = 4.5 \text{ m/sec}$$

$$\text{Speed} = \text{Wavelength} * \text{Frequency} \Rightarrow \text{Wavelength} = \text{Speed} / \text{Frequency}$$

$$\text{Wavelength} = 4.5 / 2.5 = 1.8 \text{ m}$$

24. An FM radio station operates at 99.5 MHz. What is the wavelength of the radio station to the hundredth of a meter?

$$\text{Speed of the electromagnetic wave} = \text{speed of light} = 3 \times 10^8 \text{ m/sec}$$

$$\text{Frequency of the FM radio station} = 99.5 \text{ MHz} = 99.5 \times 10^6 \text{ hz}$$

$$\text{Wavelength} = \text{Speed} / \text{Frequency} = (3 \times 10^8 \text{ m/sec}) / (99.5 \times 10^6 \text{ hz}) = 3.01 \text{ m}$$

25. The speed of sound in water is 1498 m/s. A sonar signal is sent straight down from a ship at a point just below the water surface, and 5 seconds later the reflected signal is detected. How deep is the ocean beneath the ship?

$$\text{Distance travelled by the sonar signal} = 1498 \text{ m/sec} * 5 \text{ sec} = 7490 \text{ m}$$

$$\begin{aligned} \text{Depth of the ocean floor directly below the ship} &= \text{Distance travelled by the sonar signal} / 2 \\ &= 7490 / 2 = 3745 \text{ m} \end{aligned}$$

26. A tsunami travels from California to Hawaii (around 2,500 miles) in 2.0 days and 2.0 hours. It takes about one minute for each wave to occur. What is the wavelength of the tsunami wave in kilometers? Assume 1 mile is 1.6 kilometers.

$$\text{Distance between California and Hawaii} = 2500 \text{ miles} = 2500 * 1.6 = 4000 \text{ km}$$

$$\text{Time taken by the tsunami wave} = 2.0 \text{ days and } 2.0 \text{ hours} = 50 \text{ hours}$$

$$\text{Speed of the tsunami wave} = 4000 / 50 = 80 \text{ km/hr}$$

$$\text{Period of the wave} = 1 \text{ minute} = 1/60 \text{ hr}$$

$$\text{Frequency of the wave} = 1/\text{period} = 60 \text{ 1/hr}$$

$$\text{Wavelength} = \text{Speed} / \text{Frequency} = (80 \text{ km/hr}) / (60 \text{ 1/hr}) = 1.333 \text{ km}$$

27. A source of sound emits a 600 hertz signal while moving toward you at 49 meters per second. What frequency do you hear?

Observed frequency (f)

$$f = \left( 1 + \frac{\Delta v}{c} \right) f_0 \quad \Delta v = v_r - v_s \text{ is the velocity of the receiver relative to the source.}$$

C is the speed of the wave and

f<sub>0</sub> is the original frequency.

$$\text{Observed frequency, } f = \left( 1 + \frac{49 \text{ m/sec}}{343 \text{ m/sec}} \right) * 600 \text{ hz} = 1.143 * 600 \text{ hz} = 685.71 \text{ hz}$$

28. A ray of light from air enters glass (refractive index of 1.5) at an angle of 60 degrees, what will be refracted angle of the light ray in the glass?

$$\sin(\theta_{\text{glass}})/\sin(\theta_{\text{air}}) = N_{\text{air}}/N_{\text{glass}} \quad \text{given } N_{\text{air}} = 1 \text{ and } N_{\text{glass}} = 1.5 \text{ and } \theta_{\text{air}} = 60^\circ$$

$$\sin(\theta_{\text{glass}}) = (1 / 1.5) * \sin 60^\circ = 0.5773$$

$$\text{Refracted angle of the light ray in the glass, } \theta_{\text{glass}} = \sin^{-1}(0.5773) = 35.26^\circ$$

29. An object 70 cm in front of a convex lens forms a real image of the object at a distance of 30 cm. What is the focal length of the lens?

For the convex lens, focal length (f) can be calculated as –

$$1/f = 1/D_o + 1/D_i \text{ where } D_o \text{ is distance of object and } D_i \text{ is the distance of image}$$

$$1/f = 1/70 + 1/30 = 100/2100$$

$$\text{Focal length, } f = 21 \text{ cm}$$

30. What is the Newton-Laplace equation? Using the equation calculate the speed of sound in water and steel?

The Newton–Laplace equation is used to calculate the speed of sound (c) and is given by:

$$c = \sqrt{\frac{K_s}{\rho}}, \text{ where}$$

- $K_s$  is a coefficient of stiffness, the isentropic bulk modulus (or the modulus of bulk elasticity for gases);
- $\rho$  is the density.

Bulk modulus of water ( $K_s$ ) is  $2.2 \times 10^9$  Pa and density ( $\rho$ ) of water is  $1000 \text{ kg/m}^3$

$$\text{Speed of sound in water } c = \sqrt{\frac{K_s}{\rho}} = \sqrt{\frac{2.2 \times 10^9 \text{ Pa}}{1000 \text{ kg/m}^3}} = 1483.24 \text{ m/s}$$

Bulk modulus of steel ( $K_s$ ) is  $159 \times 10^9$  Pa and density ( $\rho$ ) of steel is  $7861 \text{ kg/m}^3$

$$\text{Speed of sound in steel } c = \sqrt{\frac{K_s}{\rho}} = \sqrt{\frac{159 \times 10^9 \text{ Pa}}{7861 \text{ kg/m}^3}} = 4497.38 \text{ m/s}$$



31. What is Snell's law? Using the Snell's law find the critical angle of water and diamond?

Snell's law states that the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media, or equivalent to the reciprocal of the ratio of the indices of refraction:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

with each  $\theta$  as the angle measured from the normal of the boundary,  $v$  as the velocity of light in the respective medium,  $\lambda$  as the wavelength of light in the respective medium and  $n$  as the refractive index of the respective medium.

For critical angle ( $\theta_c$ ) in a given median, the angle of refraction in air  $\theta_{\text{air}} = 90^\circ$ .

$$\sin(\theta_{\text{c-water}})/\sin(\theta_{\text{air}}) = n_{\text{air}}/n_{\text{water}}$$

$$\sin(\theta_{\text{c-diamond}})/\sin(\theta_{\text{air}}) = n_{\text{air}}/n_{\text{diamond}}$$

$$\sin(\theta_{\text{c-water}}) = n_{\text{air}}/n_{\text{water}} * \sin(90^\circ)$$

$$\sin(\theta_{\text{c-diamond}}) = n_{\text{air}}/n_{\text{diamond}} * \sin(90^\circ)$$

$$\sin(\theta_{\text{c-water}}) = 1/1.333 * 1$$

$$\sin(\theta_{\text{c-diamond}}) = 1/2.42 * 1$$

$$\theta_{\text{c-water}} = \sin^{-1}(1/1.333) = 48.61^\circ$$

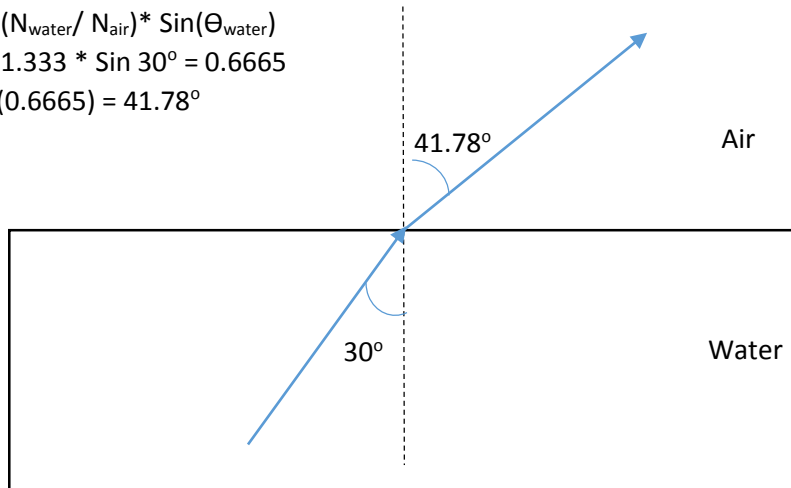
$$\theta_{\text{c-diamond}} = \sin^{-1}(1/2.42) = 24.41^\circ$$

**DRAWING QUESTIONS (5 points each) –**

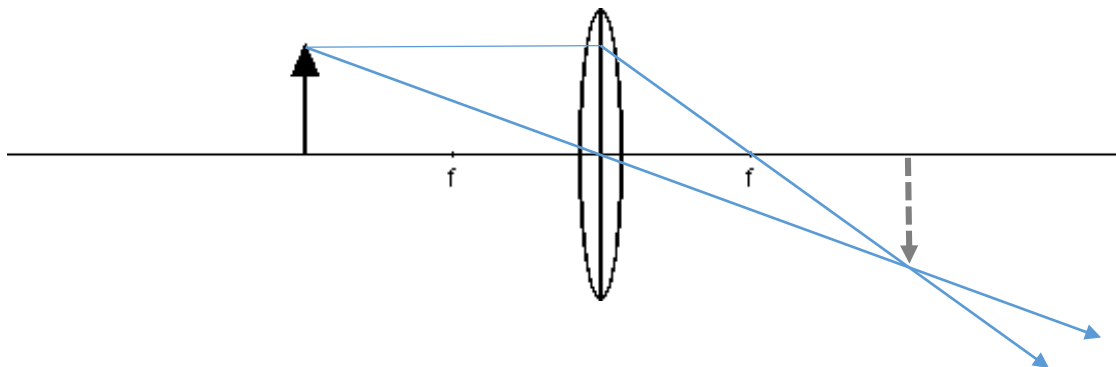
**Instruction:** Drawing should be to scale and angles should be accurate –

32. A wave is traveling through water at an angle of 30 degrees to the normal. It then encounters air at a boundary. Draw and label the normal, the incident ray, and the refracted ray and write the angle values.

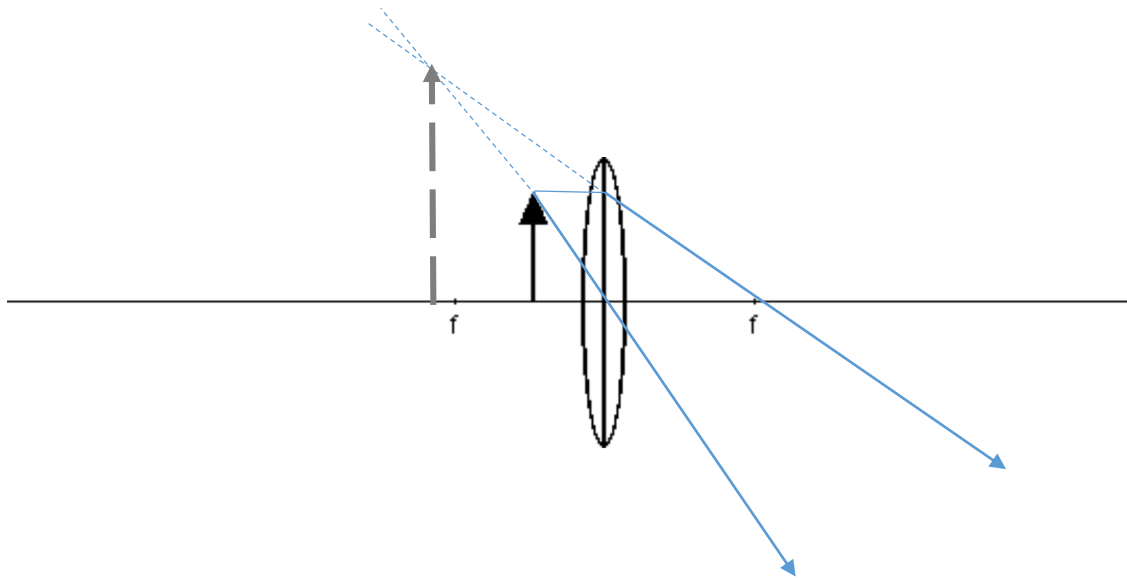
$$\begin{aligned} n_{\text{air}}/n_{\text{water}} &= \sin(\theta_{\text{water}})/\sin(\theta_{\text{air}}) \\ \sin(\theta_{\text{air}}) &= (n_{\text{water}}/n_{\text{air}}) * \sin(\theta_{\text{water}}) \\ \sin(\theta_{\text{air}}) &= 1.333 * \sin 30^\circ = 0.6665 \\ \theta_{\text{air}} &= \sin^{-1}(0.6665) = 41.78^\circ \end{aligned}$$



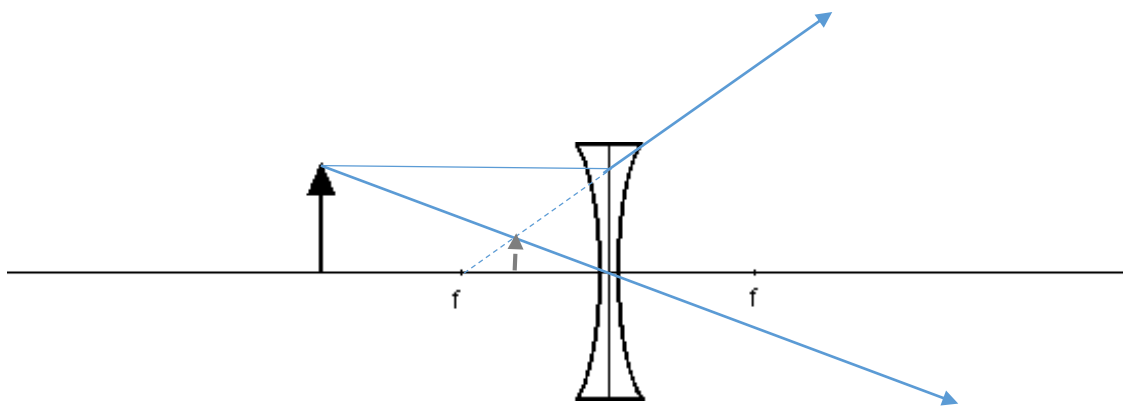
33. Draw to explain - where will the image be when the object is at twice the focal length (2f) from the convex lens? Drawing should be to scale.



34. Draw to explain - where will the image be when the object is between the focal point and the convex lens? Drawing should be to scale.



35. Draw to explain - where will the image be when an object is placed in front of a concave lens at twice the focal length ( $2f$ ) from the lens. Drawing should be to scale.



36. The drawings below show man AB with eyes at A and feet at B standing in front of a mirror. Show whether the man can see all of his reflection in mirror. Drawing should be to scale.

Yes, the man can see all of his reflection in the mirror.

